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DRSS COMMUNICATION CONSIDERATIONS FOR MANNED SPACE FLIGHT

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ABSTRACT

This paper defines a lower and an upper bound or manned space flight requirements for a Data Relay Satellite System (DRSS) in the 1975-1980 time period. In all cases, the most stringent requirement is an intersatellite link to provide wideband information transfer from an overseas DRS to the Continental United States. A parametric communication analysis is made as a function of varying frequency and antenna aperture. The desirability of using a VHF frequency band for low data rates and voice relay and the requirement for frequencies of 8 and 16 gHz for video and wideband digital data relay are shown.

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DRSS COMMUNICATION CONSIDERATIONS
FOR
MANNED SPACE FLIGHT

The manned space flight requirements for a Data Relay Satellite System (DRSS) are bounded by a minimum based on a space station mission and a maximum or nominal based on a major space base program. These are outlined below.

MINIMUM SPACE-STATION REQUIREMENTS FOR DRSS

Support

Two manned vehicles must be supported simultaneously on demand. Time sharing of DRSS support will also be a normal mode of support. The vehicles to be supported are:

1. Earth-orbiting space station

2. Manned orbiting vehicle (manned shuttle or earth-orbit phase of lunar mission)

Earth Orbit

Space station earth-orbit requirements are:

Downlink (overall bandwidth approximately 30 MHz)

1. Color TV—4-MHz baseband, approximately 20-MHz RF bandwidth

2. Digital data channel—3 Mbs

3. Eight voice channels (90 percent intelligibility) with conference capability

4. Tracking data (range and/or range rate)

Uplink

1. Color TV—4-MHz baseband, approximately 20-MHz RF bandwidth

2. Eight voice channels (90 percent intelligibility) with conferencing capability

3. Tracking data (range and/or range-rate)

4. Ten-kbs digital data link

Partial Launch Support

Requirements for partial support of launch through insertion, reentry, rendezvous, and postlanding are:

Downlink

1. One voice channel (90 percent intelligibility)

2. Tracking data (range and/or range rate)

3. Digital data channel—9.6 kbs

4. Digital data channel—72 kbs (booster during launch only)

Uplink

1. One voice channel (90 percent intelligibility)

2. Digital data channel—1 kbs

3. Tracking data (range and/or range rate)

Emergency Support

In the case of an emergency, an order-wire capability must be provided to allow immediate access through DRSS to the MCC-H. After access has been made, the following channels should be provided assuming an omni VHF antenna on the spacecraft:

1. One two-way voice channel

2. Downlink digital data channel—2.4 kbs

3. Uplink digital data channel—1 kbs

SPACE-BASE REQUIREMENTS

The requirements listed below are applicable to the medium and balanced experiment programs, which include both earth-resources and astronomy modules.

Support

Two manned vehicles must be supported simultaneously on demand. Time sharing of DRSS support will also be a normal mode of support. The vehicles to be supported are:

1. Earth-orbiting space base
2. Manned orbiting vehicle (manned shuttle or earth-orbit phase of lunar mission)

Earth Orbit

Space-base earth-orbit requirements are:

Downlink (overall bandwidth approximately 80 MHz)

1. Thirty voice channels (90 percent intelligibility) with conferencing capability
2. Digital data channel—approximately 10 Mbs
3. Tracking data (range and/or range rate)
4. Three color TV channels-approximately 20-MHz RF bandwidth per channel (quality comparable to commercial color TV)

Uplink

1. Thirty voice channels (90 percent intelligibility) with conferencing capability
2. Digital data channel—1 Mbs
3. Tracking data (range and/or range rate)

4. Three color TV channels—approximately 20-MHz bandwidth (quality comparable to commercial color TV)

Partial Launch Support

Requirements for partial support of launch through insertion, reentry, rendezvous, and postlanding are:

Downlink

1. One voice channel (90 percent intelligibility)

2. Tracking data (range and/or range rate)

3. Digital data channel—9.6 kbs

4. Digital data channel—72 kbs (booster during launch)

Uplink

1. One voice channel (90 percent intelligibility)

2. Digital data channel—1 kbs

3. Tracking data (range and/or range rate)

Emergency Support

In the case of an emergency, an order-wire capability must be provided to allow immediate access through DRSS to MCC-H. After access has been made, the following channels should be provided assuming an omni VHF antenna on the spacecraft:

1. One two-way voice channel

2. Downlink digital data channel—4.8 kbs

3. Uplink digital data channel—2 kbs

SPACE-SHUTTLE DESCRIPTION

The NASA space-shuttle concept presently envisions a shuttle vehicle which could perform the following functions:

1. Service the space station/base

2. Place and retrieve unmanned satellites in earth orbit

3. Deliver propulsive stages and payloads into earth orbit

4. Deliver propellants to the orbital propulsion system (gas station in the sky)

5. Service and maintain experiment modules

6. Support short-duration earth-orbital missions

In addition, this shuttle craft would have the following characteristics:

1. Capability to perform all onboard guidance and navigation functions for orbit manuevers, rendezvous, and reentry

2. Hard-copy readout device with automatic message checking and validation

3. Continuous voice communication capability with the ground via the space-station/base satellite communications system

4. Terminal landing capability at fields having runways of approximately 10,000 feet

COMMUNICATION LINK REQUIREMENTS ANALYSIS

A parametric study has been conducted to determine the satellite configurations that will satisfy the manned space flight requirements as stated herein. The most demanding requirement is providing sufficient communication margin for the relay of three color TV channels up and three color TV channels down. In addition, a carrier must be provided for transmission of a 10-Mbs telemetry link on the downlink and 1-Mbs data on the uplink. This paper makes no attempt to determine the optimum numbers of satellites, their position, or the location of ground stations.

Ground-to-DRS Link

For the ground-to-DRS link, a band centered at approximatley 8 gHz is assumed for the operating frequency with four separate carriers required to convey all information. An 85-foot antenna and a total of 10-kw transmit power is assumed on the ground. A 19-db receive antenna and total system noise temperature of -167 dbm/Hz is assumed on each DRS. In addition, a modulation index of 1.5 is assumed, which requires approximately 20 MHz per TV channel for a 4-MHz baseband.

A simple circuit margin calculation gives the following for nominal operation:

Ground to DRS

DRS Transmit Power, P_T (2 kw/carrier)	63 dbm
DRS Antenna Gain, G_T	64 db
Ground Antenna Gain, G_R	19 db
Space loss @ 8 kHz	-203 db
Miscellaneous Losses (antenna pointing losses, xmt and receive circuit losses, polarization loss, atmospheric losses)	-5 db
Total Received Power	-62 dbm
Noise Spectral Density, Φ_N	-167 dbm/Hz
Bandwidth (20 MHz)	73 db
S/N Ratio in f_{RF}	32 db

A S/N ratio of 32 db in the RF bandwidth for uplink TV at the DRS is more than adequate. This same S/N ratio will exist for each of the uplink TV channels.

DRS-to-Space Base Link

The link between DRS and the space base is of much more concern. Not only will this link be ERP-limited per RF channel but sufficient power must be provided for three wideband (20-MHz channel) channels. The desired S/N in a 20-MHz band at the space base is 15 db. Since the S/N of a 20-MHz channel on the ground-to-DRS link is very high (32 db, determined above), the S/N of the corresponding channel on the DRS-to-space base link must essentially be 15 db, which will result in essentially no degradation in the repeater.

A parametric analysis, given below, of antenna sizes on the space base and DRS, and power required versus operating frequency is the most convenient way of analyzing this link. A frequency-translation repeater is assumed in which all four uplink RF channels are either downconverted or upconverted depending on the DRS-space base frequency. The basic calculation will be carried out at 2 gHz for one TV link. The DRS transmit power is the unknown X and Y is the space-base antenna gain. X and Y are determined in order to achieve a S/N ratio of 15 db in 20 MHz, which will give approximately 28 db S/N at baseband.

<u>DRS to Space Base</u>

DRS Transmit Power, P_T	Xmw/TV channel
DRS Antenna Gain, G_T (4' dish at 2 MHz)	26 db
Space Loss	-193 db
Miscellaneous Losses	-4 db
Ground Antenna Gain, G_R	Y db
Total Received Power	[10 log X + Y - 171] dbm
Noise Spectral Density, Φ_N	-168 dbm/Hz
$\Phi_N + 10 \log (20 \times 10^6)$	-95 dbm
S/N (in 20 MHz)	10 log X + Y - 76

The FM improvement factor is $3\beta^2\left(\frac{\Delta f}{fm}\right)$. For $\beta = 1.5$,

$$10 \log 3\beta^2\left(\frac{\Delta f}{fm}\right) = 12.3 \text{ db.}$$

An rms signal-to-rms noise of 27.3 db in the TV baseband is considered adequate; thus a S/N ratio of 15 db is desired in a 20-MHz bandwidth, or

$$10 \log X + Y - 76 = 15,$$

$$10 \log X + Y = 91 \text{ db.} \qquad \text{(4' dish on DRS at 2 gHz)} \qquad \text{(A)}$$

In the above equation, X is the DRS transmit power per RF channel and Y is the space-base antenna gain. For an 8-foot antenna on DRS, Equation A becomes

$$10 \log X + Y = 85.5 \text{ db.} \qquad \text{(8' dish on DRS at 2 gHz)} \qquad \text{(B)}$$

It is assumed that an additional 0.5 db pointing loss occurs in the 8-foot antenna over the 4-foot antenna.

For a 16-foot antenna on DRS, Equation A becomes

$$10 \log X + Y = 80 \text{ db.} \qquad \text{(16' dish on DRS at 2 gHz)} \qquad \text{(C)}$$

An additional pointing loss of 1 db is assumed for the 16-foot antenna over the 4-foot antenna. The simplifying assumption has been made that surface tolerances are identical for all three antennas.

The 1-Mbs uplink data channel requirements will obviously be different than an uplink TV channel. This difference is assumed to exist in the DRS transmit power since Y (space-base antenna gain) will be identical for all four uplink channels. However, since 15 db is required in 20 MHz for a TV channel and only 12 db is required in 1 Mbs for the data channel, the 1-Mbs channel power will be negligible compared to the TV channel power requirements and will thus be ignored.

In order to make the analysis complete, it is necessary to make a comparison of the links operating at 2, 8, and 16 gHz. For a fixed aperture on DRS, the total link gain at 8 gHz over 2 gHz is 0 db. However, a total difference of -1 db is allowed due to increased noise figures. Equations A, B, and C then become

$$10 \log X + Y = 92 \text{ db,} \qquad \text{(4' dish on DRS at 8 gHz)} \qquad \text{(D)}$$

$$10 \log X + Y = 86.5 \text{ db,} \qquad \text{(8' dish on DRS at 8 gHz)} \qquad \text{(E)}$$

$$10 \log X + Y = 81 \text{ db.} \qquad \text{(16' dish on DRS at 8 gHz)} \qquad \text{(F)}$$

For a fixed aperture on DRS, the total link gain at 16 gHz over 8 gHz is 0 db. However, a total difference of -1.0 db is again assumed because of degradation in noise figures. Equations D, E, and F now become

$10 \log X + Y = 93$ db,	(4' dish on DRS at 16 gHz)	(G)
$10 \log X + Y = 87.5$ db,	(8' dish on DRS at 16 gHz)	(H)
$10 \log X + Y = 82$ db.	(16' dish on DRS at 16 gHz)	(I)

Equations A through I are solved for dish sizes of 4, 8, and 16 feet on the space base and the results are presented in Table 1. The power in each box is the total power required. It is felt that 50, 30, and 20 watts are reasonable upper limits for total DRS transmit power at 2, 8, and 16 gHz, respectively.

The space base will be able to generate considerably more power than a DRS. Thus, the limiting link is the link from DRS to the space base as indicated in Table 1. Once a reasonable transmit power is decided upon for DRS, the antenna sizes are fixed. In the high-gain mode, the only significant difference between the uplink and downlink is the increase from 1 Mbs to 10 Mbs. The S/N required in the bit-rate bandwidth is 12 db. Assuming the RF bandwidth is 20 MHz, then a S/N of 9 db is required in the 20-MHz data channel. The 10-Mbs channel will differ from a 20-MHz TV channel by 6 db (S/N required in a 20-MHz TV channel = 15 db). Thus, to determine the total minimum transmit power from the space base required to support three TV channels and one 10-Mbs channel, the numbers in Table 1 must be multiplied by a factor of 13/12. The 30 duplex voice channels have not been considered in the previous calculation. The additional power required to support them is a small percent of the power required for a TV link.

It may be desirable for the DRSS to have an interrelay satellite link that will support the entire uplink and downlink spectrum. Obviously, the interrelay link will degrade these signals in each repeater. The TV channels in the link between DRS and the space base have been structured for 15-db S/N ratio in 20 MHz. In order to preserve this S/N to within 1 db, the S/N of a 20-MHz channel on the interrelay link should be 6 db higher, i.e., 21 db.

Table 1 is used as a basis for the intersatellite matrix of Table 2 with the assumptions that the noise figures and antenna pointing losses are comparable to the DRS-to-space base link. In addition, an additional 4 db in space loss is assumed for the intersatellite link over the DRS-to-space base link due to the increased range. Therefore, a total increase in link gain of 10 db is required.

In Table 2, the S-band frequency has been eliminated since in all cases, the DRS power required is completely unreasonable. Table 2 indicates that, in order to keep the transmit power to a reasonable level, a 16-foot antenna is required on each end of the link.

Tables 3 and 4 are the corresponding charts for the minimum requirements. The pacing requirement in each link is the relay of one color TV channel.

Space Base-to-DRS Link

The space base will have a power plant capable of generating 100 kw. It is assumed herein that the technology in power amplifiers will be such that at least 50, 30, and 20 watts can be generated at 2, 8, and 16 gHz, respectively. For the space base-to-DRS link, a total transmit power of 50, 30, or 20 watts per channel would be available. Since the DRS-to-space base link sets the antenna sizes and since more power can be generated on the space base, the space base-to-DRS links will be better than the DRS-to-space base link. A 20-MHz channel on the downlink intersatellite link was designed for a S/N ratio of 21 db. The output channel S/N ratio at the second DRS under this condition will be 18 db in 20 MHz for each TV channel.

DRS-to-Ground Link

In order to calculate the requirements for the DRS-to-ground-link, it is assumed that a S/N of 15 db is required at the ground on each 20-MHz channel. The space base is assumed to have enough transmit power to achieve a S/N of 21 db in each 20-MHz channel at the first DRS. A 20-MHz TV channel on the interrelay link was designed to achieve a S/N of 21 db. Thus the S/N at the second DRS will be 18 db. In order to obtain a S/N of 15 db on the ground, the S/N ratio in a 20-MHz channel on the DRS-to-ground link must be 18 db.

DRS To Ground

DRS Transmit Power, P_T	X mw/channel
DRS Antenna Gain, G_T	Y db
Space Loss (at 7 kHz)	-201 db
Miscellaneous Losses	-4 db
Ground Antenna Gain, G_R (85' at 7 kHz)	63 db

Received Power	$[10 \log X + Y - 142]$ dbm
Noise Spectral Density, Φ_N	-176 dbm/Hz
$\Phi_N + 10 \log (20 \times 10^6)$	-103 dbm

S/N Ratio = 18 db = $10 \log X + Y - 39$
or $10 \log X + Y = 57$ db

Considering the other power requirements already imposed on DRS, the transmit power per channel should not exceed 5 watts for a total transmit power slightly less than 20 watts. Under this condition Y = 20 db. This corresponds approximately to an earth-coverage antenna on each DRS at 7 kHz.

Booster Requirements

Most of the requirements for supporting the shuttle or parking orbit of a lunar mission can be met by utilizing VHF frequencies. The most difficult requirement to support is a 72-kbs link from a booster. Several adjacent clear channels would be required. The following calculation illustrates the type of VHF ERP required on the booster.

$10 \log (P_T G_T$ [Booster ERP])	X dbm
Space Loss (at 140 MHz)	-168 db
Miscellaneous Losses	-3 db
DRS Antenna Gain, G_R	16 db
Noise Spectral Density, Φ_N	-170 dbm/Hz
$\Phi_N + 10 \log 7 \times 10^4$	-121.5 dbm
S/N	X$-$33.5

It is assumed that the data is coherent PSK requiring 12-db S/N in the bit rate bandwidth for 10^{-6} BER, or

$S/N = 12 = X-33.5,$

$X=45.5.$

If the VHF antenna on the booster were a perfect omni, a transmit power of 35 watts would be sufficient. The antenna cannot be considered perfect, so it is recommended that the booster transmit 70 watts to provide the necessary margin. Table 5 shows the type of ERP required from the booster as a function of frequency and the two DRS antenna gains of 16 db and 22 db. It clearly demonstrates that for this link structure, the lower frequencies are much more desirable.

Table 6 represents the ERP required on the space base in order to support an emergency voice link, assuming a 26-degree antenna (16-db gain) on the DRS. The last column indicates the transmitter power requirements when the space base uses an omnidirectional antenna. In order to transmit 4.8-kbs TLM simultaneously with voice, approximately 3 db must be added to the ERP number and the transmit power should be multiplied by 2.

CONCLUSIONS

In order to support manned flight requirements, an 8-foot antenna on the DRS is recommended (Table 1), operating at 8 gHz. This assumes a 16-foot antenna on the space base, which is a very reasonable assumption. This same conclusion is true in order to meet the minimum requirements.

It appears that a 16-foot antenna is required on each DRS for the inter-satellite link operating at either 8 gHz or 16 gHz for support of the nominal requirements. To support the minimum requirements, 8-foot antennas operating at 16 gHz and transmitting 50 watts are needed. Fifty watts at 16 gHz is not considered feasible. The losses used in this paper would have to be reduced by 3 db or more to achieve a reasonable power level or a dish slightly larger than 8 feet is required. Table 5 indicates that for satisfying the requirements of the second vehicle (space shuttle for earth-orbit phase of lunar mission), a frequency of operation somewhere between 136 MHz and 400 MHz should be used. Table 7 shows the DRS antenna sizes required if this requirement must be met at 2, 8, or 16 gHz.

Tables 8 and 9 compare the various DRS spacecraft configurations with respect to their ability to meet both the minimum as well as the nominal manned space flight requirements. In both figures, it is assumed that a system operating somewhere between 136 MHz and 400 MHz can be added to any DRS spacecraft configuration to cover the space shuttle and earth-orbit phase of a lunar mission. If this requirement must be met at 2, 8, or 16 gHz, none of the configurations are adequate.

It is important to note that if the space shuttle requirements can be met at a low frequency, the DRS antenna required to support the second manned vehicle would be approximately earth coverage. In this case, only two other antennas would be required on DRS, one for the DRS-to-space base link and one for the intersatellite link.

Table 1

Total Power Required for DRS-to-Space Base Link for Three Color TV Channels and 100-kbs Data Channel

Space-Base Antenna	Frequency (gHz)	DRS Antenna-Power Requirements (watts)			
		4'	8'	16'	32'
4'	2	9450	2700.0	750.0	215.0
	8	750	210.0	60.0	17.0*
	16	237	66.0	19.0**	5.4**
8'	2	2370	600.0	190.0	54.0*
	8	190	52.5	15.0*	4.3*
	16	60	16.5*	4.8**	1.4**
16'	2	600	168.0	48.0*	14.0*
	8	48	13.5*	3.75*	1.0*
	16	15*	4.2*	1.2**	0.34**

*Feasible power and antenna tolerances
**Feasible power; antenna tolerances questionable

Table 2

Total DRS Transmit Power Required for Intersatellite Link for Relay of Three Color TV Channels and 100-kbs Data Channel

DRS #2 Antenna	Frequency (gHz)	DRS #1 Antenna-Power Requirements (watts)		
		4'	8'	16'
4'	8	7500	2100	600.0
	16	2370	660	190.0
	60	150	-	-
8'	8	1900	525	150.0
	16	600	165	48.0
16'	8	480	135	37.5*
	16	150	42	12.0**

*Feasible power and antenna tolerances
**Feasible power; antenna tolerances questionable

Table 3

Total DRS Transmit Power Required for DRS-to-Space-Base Link to Relay One Color TV Channel and 10-kbs Telemetry

Space-Base Antenna	Frequency (gHz)	DRS Antenna-Power Requirements (watts)			
		4'	8'	16'	32'
4'	2	3150	900.0	250.00	70.00
	8	250	70.0	20.0*	5.70*
	16	79	22.0*	6.30**	1.80**
8'	2	790	220.0	63.00	18.00*
	8	63	14.0*	5.00*	1.40*
	16	20*	5.5*	1.60**	0.50**
16'	2	200	56.0*	16.00*	5.00*
	8	16*	4.5*	1.25*	0.35*
	16	5*	1.4*	0.40**	0.10**

*Feasible power and antenna tolerances
**Feasible power; antenna tolerances questionable

Table 4

Total DRS Transmit Power Required for Intersatellite Link to Relay One Color TV Channel and 3-Mbs Telemetry

DRS #2 Antenna	Frequency (gHz)	DRS #1 Antenna-Power Requirements (watts)		
		4'	8'	16'
4'	8	2500	700	200.0
	16	790	220	63.0
	60	50	-	-
8'	8	633	175	50.0
	16	200	55	16.0**
16'	8	160	45	12.5*
	16	50	14**	4.0**

*Feasible power and antenna tolerances
**Feasible power; antenna tolerances questionable

Table 5

Required Booster ERP for S/N = 12 db in Bit-Rate Bandwidth (50 kHz)
(losses and NF have been taken into account)

Frequency (gHz)	DRS Antenna Effective Radiated Power Requirements (dbm)	
	26° BW - 16db Gain	13° BW - 22db Gain
.136	45.0	39.0
.260	51.0	45.0
.400	56.0	50.0
2	70.5	64.5
8	84.5	78.5
16	91.5	85.5

Table 6

Space Base ERP and Transmit Power for Emergency
Voice Assuming a 16-db (26°) Antenna on DRS

Frequency (gHz)	Space Base ERP (dbm) (S/N = 10 db)	Transmit Power With Omni on Space Base (watts)
.136	36	8
.260	42	15
.400	45	30
2	62	1,500
8	76	80,000
16	83	200,000

Table 7

Required DRS Antenna Size for Near-Omni Antenna on Space Shuttle or CSM

Frequency (gHz)	Transmit Power (watts)	DRS Antenna Size (feet)
2	50	20
8	30	30
16	20	50

Table 8

Configuration Comparison for Minimum Requirements

Configuration	Weight (lb)	Power (watts)	Attitude Control	Antennas	Frequency (gHz)	DRS to Space Station	Intersatellite
GSFC A	805	255	Dual Spin	8' Dish	2	No	No
GSFC B	970	350	Dual Spin	8' Dish	Dual Feed 2 and 8	Yes	No
GSFC C	1000	350	Dual Spin	8' Dish	16	Yes	Yes
				4' Dish	8		
GSFC D	1350	500	3 Axis	Two 8' Dishes	Dual Feed 2 and 16	Yes	Yes
GSFC E	1650	600	3 Axis	16' Dish	16	Yes	Yes
				Two 8' Dishes	8		
GSFC F	2150	650	3 Axis	Two 16' Dishes	16	Yes	Yes
				Two 16' Dishes	Dual Feed 2 and 8		
JPL Dual Access	1340	510	3 Axis	Two 15' Dishes	Dual Feed .400 and 16	Yes	Yes
JPL Interrelay	1540	650	3 Axis	Three 8' Dishes	16	Yes	Yes
				Disc on Rod	.136		
JPL Dual Purpose	1970	750	3 Axis	Four 8' Dishes	16	Yes	Yes
				Disc on Rod	.136		

Note: The above entries assume a system operating somewhere between 136 MHz and 400 MHz can be added to cover the space shuttle and earth-orbit phase of a lunar mission. If this requirement must be met a 2, 8, or 16 gHz, then none of the above configurations are adequate.

Table 9

Configuration Comparison for Nominal Requirements

Configuration	Weight (lb)	Power (watts)	Attitude Control	Antennas	Frequency (gHz)	DRS to Space Station	Intersatellite
GSFC A	805	255	Dual Spin	8' Dish	2	No	No
GSFC B	970	350	Dual Spin	8' Dish	Dual Feed 2 and 8	Yes	No
GSFC C	1000	350	Dual Spin	8' Dish	16	Yes	No
				4' Dish	8		
GSFC D	1350	500	3 Axis	Two 8' Dishes	Dual Feed 2 and 16	Yes	No
GSFC E	1650	600	3 Axis	16' Dish	16	Yes	Yes
				Two 8' Dishes	8		
GSFC F	2150	650	3 Axis	Two 16' Dishes	Dual Feed	Yes	Yes
				Two 16' Dishes	2 and 8		
JPL Dual Access	1340	510	3 Axis	Two 15' Dishes	Dual Feed .400 and 16	Yes	Yes
JPL Interrelay	1540	650	3 Axis	Three 8' Dishes	16	Yes	No
				Disc on Rod	.136		
JPL Dual Purpose	1970	750	3 Axis	Four 8' Dishes	16	Yes	No
				Disc on Rod	.136		

Note: The above entries assume a system operating somewhere between 136 MHz and 400 MHz can be added to cover the space shuttle and earth-orbit phase of a lunar mission. If this requirement must be met at 2, 8, or 16 gHz, then none of the above configurations are adequate.